Autonomous Research Vessels for Adaptive Upper-Ocean Process Studies

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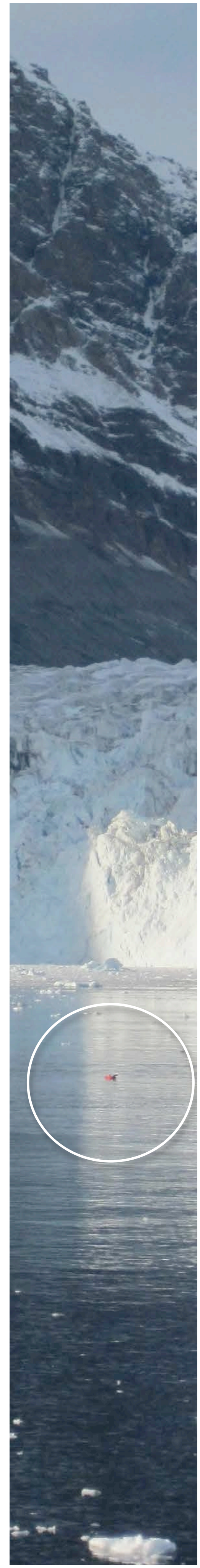
Award N00014-14-1-0490 / Annual Report, 2014



LONG-TERM GOALS

We seek to obtain a more complete and fundamental understanding of the hierarchy of processes that transfer energy and momentum from large scales (bot atmosphere and ocean) to the microscale, which help set the vertical structure and horizontal variability of upper ocean heat content and salinity variability. A primary focus is to measure the interplay between these finescale dynamics and turbulence, which ultimately drives the irreversible heat/freshwater transports. The turbulent cascade impacts the acoustic, optical, and biogeochemical propertie of the water column, and feeds back to alter the larger scale circulation. We emphasize observations, innovative sensor / instrumentation development and integration, and process-oriented internal wave and turbulence modeling for interpretation.

OBJECTIVES

This award is supporting the development of Autonomous Research Vessels (ARVs) for the purpose of obtaining uncontaminated near-surface temperature salinity and velocity. These platforms are to be used to characterize upper-ocean acoustics, understand the dynamics that control upper ocean heat and salinity variability, and to operate efficiently and i locations or in ways that are not practical/possible from traditional research vessels. Initial testing will occur on the Oregon and California coasts, followed by open-ocean tests in the Bay of Bengal. We anticipate performing coordinated transects in summer 2015 to complement the deeper, coarser sampling from the R/Vs Revelle and Sagar Nidhi.

The objective is to develop and demonstrate the utility of Autonomous Research Vessels for the purpose of providing **(1) open-ocean sampling in parallel to traditional research vessels, and (2) an uncontaminated view of the near-surface ocean with <1 m vertical and horizontal resolution.** Such sampling will provide a unique view of the upper few meters of the water column during ASIRI and will provide spatial context for drifting arrays while the mother ship is engaged in other activities. With adaptive scientific missions guided remotely via radio and/or satellite communications, we intend this technology to have **broad application for a variety of open-ocean and/or coastal studies.**

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2014**	2. REPORT TYPE	3. DATES COVERED **00-00-2014 to 00-00-2014**

4. TITLE AND SUBTITLE **Autonomous Research Vessels for Adaptive Upper-Ocean Process Studies**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Oregon State University,College of Earth, Ocean, and Atmospheric Sciences,104 CEOAS Administration Building,Corvallis,OR,97331-5503**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

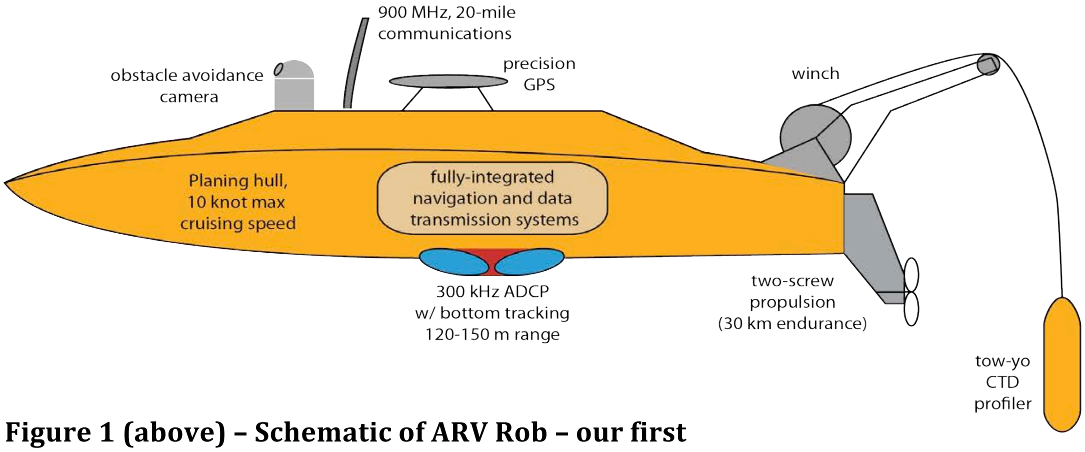
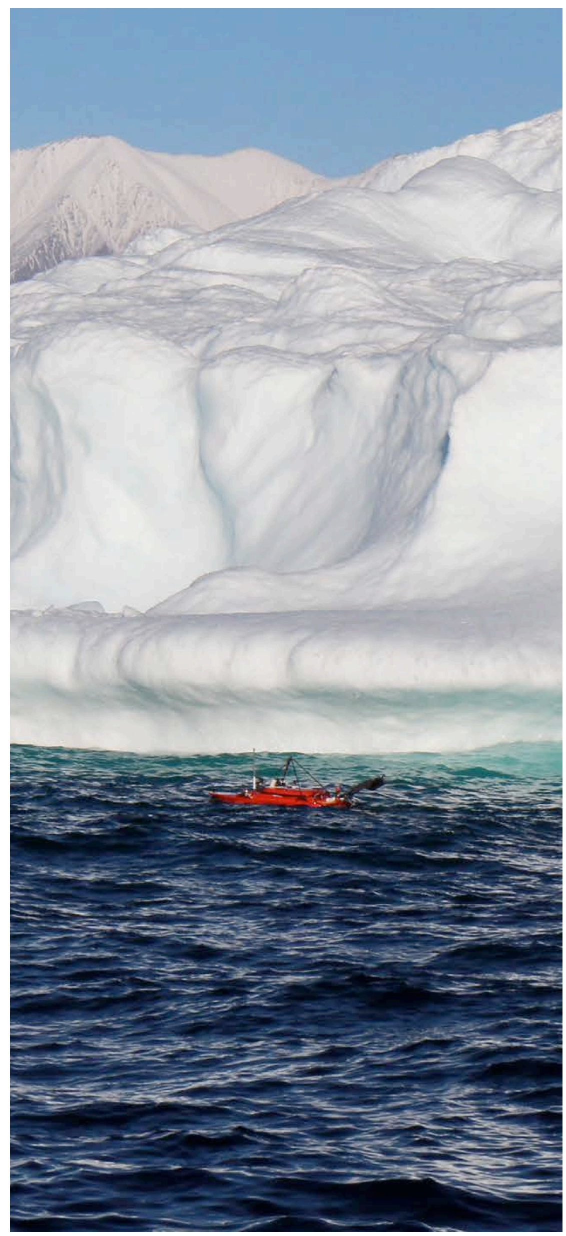


Figure 1 (above) – Schematic of ARV Rob – our first autonomous research vessel used for ADCP and CTD profiling in Greenland Fjords.

Figure 2 (below) AR Rob acquiring CTD cast (and ADCP profiles) within m of a Greenland iceberg.



APPROACH:

Our first ARV (ARV Rob) was based on OceanScience's Q-boat, and was first used in summer 2013 to sample within 500 m of the terminus of Kangerdlugssup Sermerssua, a larg Greenland outlet glacier, and within meters of large icebergs. This vehicle was specifically developed for fjord research, so is small (2 m long) with relatively short endurance (<4 h and limited seaworthiness (tested only in waves < 1m). It was retrofitted in 2014 with a new short-baseline GPS-based heading system (a prototype from Hemisphere GNSS) that we have been testing for integration into our navigation systems. In parallel, we are developing a new line of vessels designed for offshore use. Our second is an electric ARV (donated by Eric Terrill) that is being used for developing and testing updated control electronics and communications systems. The third is a gasoline/jet-propelled kayak based on the Mokai platform. All ARVs have high-frequency ADCPs and can provide velocity data to within 1 m of the ocean surface. Our current ARVs have active A-frames and profiling CTD systems to perform tasks similar to that of the mother ship. The advantages of ARVs are numerous: (1 they can collect velocity and hydrographic data in the upper 2-3 m of the water column because of their shallow drafts and high-frequency instrumentation, (2) they enable us to obtain simultaneous measurements of the horizontal variability, providing spatial (3D) context and permittin calculation of relative vorticity, etc.

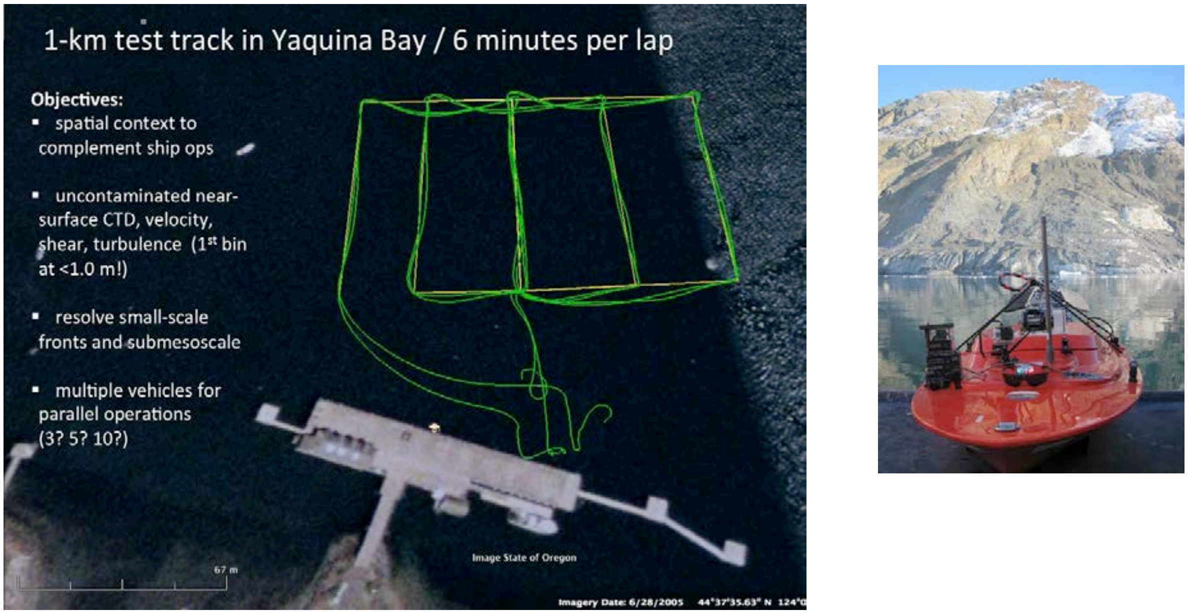


Figure 3 – Left: Autonomous sampling performed by ARV Rob in Yaquina Bay, Oregon, during sea trials in summer 2013. Green lines show vessel track for two, 6-minute long survey lines that were requested along the yellow radiator pattern. Right: ARV Rob awaiting mission instructions on the fantail of the R/V Sanna in Greenland.

RESULTS:

We have demonstrated that ARV Rob can perform automated missions (Fig. 3) for reasonable durations and with sufficient reliability for routine sampling. As an example, data from a 1.5 hour mission to study the dynamics of iceberg wakes is shown below. During this period, R/V Rob acquired ADCP data and 15 CTD profile (one every 6 minutes) to 120 m depths (Fig. 4). **These data rates exceed those of the mother ship** R/V Sanna, and were obtained **within meters of an unstable iceberg**; moreover, data were **uncontaminated as shallow as 1 m from the ocean surface.** However, ARV Rob is a small, fully electric vessel ideal for short missions in protected fjords, and not suitable for long-term, ope ocean work.

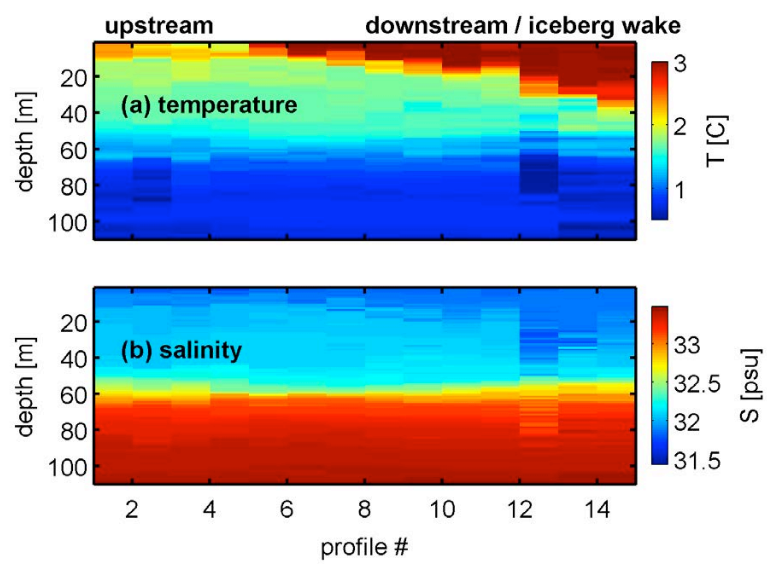


Figure 4 – CTD profiles acquired in Sept 2013 by ARV Rob as it circumnavigated an iceberg; profiles 1-7 are upstream, while profiles 11-15 are downstream and sample the iceberg's warm, freshwater wake.

This past summer we modified our electrically-propelled roboyak to gain a Linux/PC based control system with the goal of extending its mission robustness, adaptabilit and science capabilities beyond that of the Arduino-based ones. Physics student Andrew Stuntz led this effort and will present results at the International Conference on Robotics and Automation (ICRA) this spring (Stuntz et al, 2014). We are continuing to develop these control systems and longer-range communications for open–ocean work. In parallel, we are refining our automated CTD profiler, winch and A-frame to have increased reliability in larger seas.

We are still awaiting delivery of the hull for our third ARV (ARV III) which is a new generation vessel based on the Mokai jet-kayak platform (Fig 5), which will be similar to some of the jet kayaks used by WHOI, but will incorporate more reliable CTD and control systems, and be adapted for longer range sampling.

Figure 5 – The Mokai gasoline/jet propelled kayak can cruise at speeds up to 20 knots and has multi-day endurance at lower speeds (stock photo/ we are still awaiting delivery of the hull).

RELATED PROJECTS:

We plan to complement the autonomous profiling and shipboard surveying in the summer of 2015 with ARVs to quantify the upper ocean temperature, salinity and velocity variability on horizontal scales of 10 m to 10 km, and to within 1 meter of the ocean surface. Figure 6 shows an example of the type of sampling we envision there are many other modes possible, depending on the experiments underway:

1. ARV transects parallel to the mother ship to sample the surface boundar layer in an uncontaminated way and allow potential vorticity to be calculated.
2. repeated ARV grids around fixed or Lagrangian drifting arrays (wirewalkers + sparbuoy) to provide the a 3D spatial context, or perform repeated grids at a scale the complements that of mother-ship sampling.
3. simultaneous ARV spatial surveys while the mother ship is occupie deploying other instruments and/or doing deeper CTD casts.

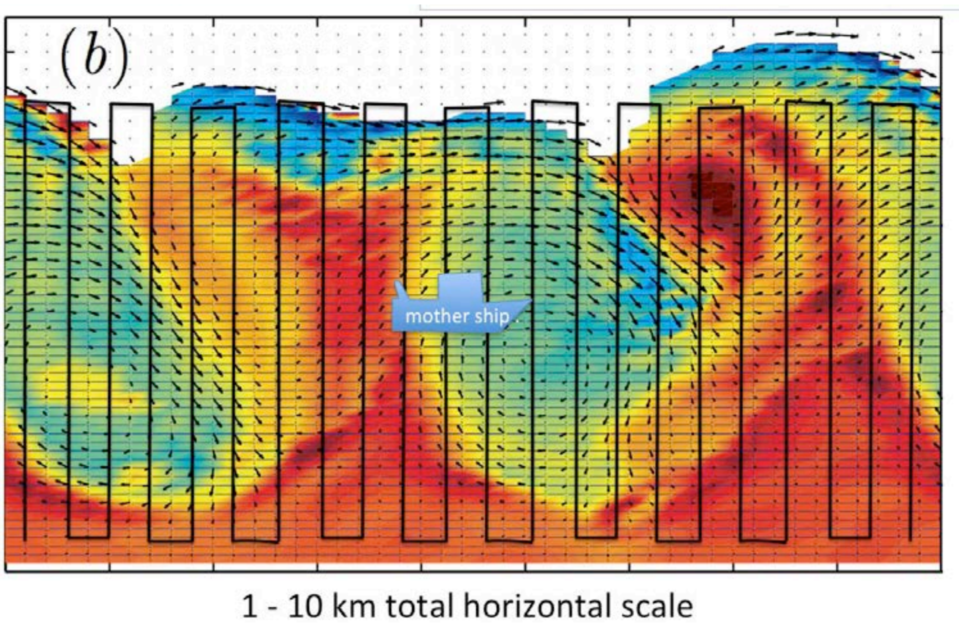


Figure 6 –Proposed ARV sampling to study small-scale variability in the Bay of Bengal. Color image represents potential vorticity (adapted from Thomas, Tandon and Mahadevan, 2008). The radiator pattern sketched is schematic and scales with the size of the feature to be sampled; if the total domain is km wide, then the plotted track can be repeated in 2 h with 50 m sample/profile spacing. Alternatively, if the domain is 1 km wide, profile spacing would be 500 m and the radiator (100 km long) would be repeated every 24 h.

SYNERGIES:

ARV developments will be coordinated with Eric Terrill, who is developing a paralle set of platforms at UCSD, and we plan to use our vehicles in tandem in future research initiatives.

PUBLICATIONS:

A. Stuntz, S-H Yoo, Y. Zhang, R. Rothschild, G.A. Hollinger and R.N. Smith, 2014: Experimental Analysis of Receding Horizon Planning Algorithms for Marine Monitoring, Proceedings of the ICRA, [submitted]

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A. Stuntz, S-H Yoo, Y. Zhang, R. Rothschild, G.A. Hollinger and R.N. Smith, 2014: Experimental Analysis of Receding Horizon Planning Algorithms for Marine Monitoring, Proceedings of the ICRA, [submitted]

Thomas, L. N., A. Tandon, and A. Mahadevan, 2008. Sub-mesoscale processes and dynamics. In M. W. Hecht, and H. Hasumi (Eds.), Ocean Modeling in an Eddyin Regime, Geophysical Monograph Series, Volume 177, American Geophysical Union Washington DC, pages 17-38